REMARKS

Claims 1-11 are currently pending in this Application. Claim 9 is amended with this response. Applicant has respectfully attached a copy of the requested translation.

Claim Rejections Under 35 U.S.C. §102(b)

Claims 1-11 are rejected under 35 U.S.C. §102(b) as being anticipated by NPL to Volker Deutsch (hereinafter "Deutsch"). Applicant respectfully traverses the rejections.

"A claim is anticipated only if each and every element as set forth in the claim is found, either expressly or inherently described, in a single prior art reference." *Verdegaal Bros. V. Union Oil Co. of California*, 814 F.2d 628, 631, 2 USPQ2d 1051, 1053 (Fed. Cir. 1987).

Applicant's claim 1 recites,

"An apparatus for planning preparing, performing and evaluating a non-destructive inspection of a test object having... a *standardized* data processing program... selecting at *least one determined test instrument from a group of test instruments*...[and]... establishing a test scheme, with all predetermined settings being *transferred to the respective test instrument upon connection thereof so that it is preset for inspection*"

Deutsch does not teach a "standardized" software program. In fact, it is actually not possible to plan a whole workflow or testing process (as can be done with a standardized software program) via the single apparatus taught in Deutsch. Further, there is no teaching in Deutsch whatsoever of selecting at least one determined test instrument from a group of test instruments, as is recited in Applicant's claim 1, nor is there any teaching of predetermined settings being transferred to respective test instrument upon connection thereof for a preset inspection (allowing a preset for inspection), as is also recited in Applicant's claim 1.

It should be noted that, an exemplary embodiment of the apparatus recited in Applicant's claim 1, the apparatus may allow an organization of a whole workflow with just one device. For each step of the workflow, particular sub-steps/analyzations are thus rendered possible. Use of the *standardized* software programs allow use of more or less every any device that can communicate with the standardized interface. For example, the device can therefore use standardized data (for printing, displaying, etc.) with such common Microsoft programs as PowerPoint, Word, and Excel.

Since Motzer fails to teach or suggest all of the limitations of claim 1 or the now independent claim 9, Applicant respectfully submits that neither claim 1 nor 9, nor claims 2-8 and 10-11 that depend respectively therefrom, are anticipated by Deutsch.

Conclusion

All of the objections and rejections are herein overcome. In view of the foregoing, it is respectfully submitted that the instant application is in condition for allowance. No new matter is added by way of the present Amendments and Remarks, as support is found throughout the original filed specification, claims and drawings. Prompt issuance of Notice of Allowance is respectfully requested.

The Examiner is invited to contact Applicant's attorney at the below listed phone number regarding this response or otherwise concerning the present application.

Applicant hereby petitions for any necessary extension of time required under 37 C.F.R. 1.136(a) or 1.136(b) which may be required for entry and consideration of the present Reply.

If there are any charges due with respect to this Amendment or otherwise, please charge them to Deposit Account No. 06-1130 maintained by Applicant's attorneys.

Respectfully submitted,

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3.2 Ultrasonic Test Equipment

Fig. 3-16 shows the design of an ultrasonic test unit diagrammed schematically. A pulse generator (clock generator) triggers short electric pulses in rapid sequence in the transmitter, generating sound pulses in the test head, the frequency and bandwidth of the sound pulses depending on their acoustic properties. The sound pulses (echoes) returning from the workpiece are converted by the same test head into electric signals, which are sent to the vertical deflection amplifier of a cathode ray tube. Its horizontal deflection forms the time base as in an oscilloscope. The various pulses are therefore represented on the screen in their chronological order as vertical deflection with respect to the baseline. The display screen begins at the left with the *transmission pulse* SI. As the electron beam is deflected to the right in a time-proportional deflection, reflection from the defect surface as *defect echo* FE and the *back wall echo* RE both appear at the correct interval from one another and from the transmission pulse. This is repeated with each following transmission pulse. Because of the short transit times in the workpiece, it is possible to work with 100 to 1000 pulses per second, depending on the velocity of sound and the test ranges, so that for the human eye, a standing image appears in which the depth position of defects can be assigned accurately to transit times on the time base. Such a representation of the echo amplitudes over transit time is referred to as the *A-image*.

The number of transmission pulses generated per second is known as the *pulse repetition frequency PRF*. This is usually given by the manufacturer of most equipment and varies with the test range setting. The more rapidly the pulses follow one another, the lighter the display appears on the screen and the more rapidly a test object can be brought into the next test position from one pulse to the

next in automatic testing. However, there is an upper limit to the maximum pulse repetition frequency. The interval between two successive pulses must be so great that the reflections triggered by the previous pulse in the workpiece have completely subsided. If this is not the case, so-called "phantom echoes" may occur, simulating [nonexistent] defects, when working with a high gain and materials having good sound conduction (Fig. 3-17).

To illustrate the test findings, the electric pulses coming from the test head are processed further in a wide variety of ways. In addition to playback that is true to nature, so-called HF (high frequency) display, the pulses can be rectified and filtered and minor defects of no interest can be filtered out by using a threshold value (Fig. 3-18). A distinction is made here between a *linear threshold*, in which no more echoes beneath the threshold value are displayed, and the *nonlinear threshold* in which the entire A image is lowered by the amount of the threshold. In addition, many devices also allow a phase-rotated pulse display (Fig. 3-19).

Horizontal and vertical deflection must be exactly in proportion to the transit time and amplitude of the echo pulses. This required *linearity* can be controlled easily: multiple echoes from a defect-free workpiece must all be the same distance from one another. With accurate measurement, it is then also found that the distance between the start of the transmission pulse and the first back wall echo is slightly greater than the distance between two successive echoes. This is due to the additional transit time within the protective layer and/or the delay path and due to a slight time lag between the electric transmission pulse and the impingement of sound into the workpiece, i.e., the acoustic transmission pulse. Fig. 3-20 illustrates this state of affairs.

Fig. 3-16. Basic design of ultrasonic test equipment:

transmitter; SE switch; test head; workpiece

rectifying filtering threshold gain

[vertical] deflection amplifier; cathode ray tube

[far left] pulse generator

pulse shift test ranges (sawtooth generator); horizontal deflection amplifier

Fig. 3-17. Occurrence of phantom echoes when the pulse repetition frequency is too rapid (bottom).

Pulse interval large enough

Pulse interval too small

Fig. 3-18.

a) Non-rectified and/or HF signals

b) Rectified signals: left: one-way rectification positive, center: double-way (two-way) rectification, right: one-way rectification negative

c) Filtered signals, threshold shown with dotted line; left: nonlinear threshold, right: linear threshold

d) Amputation reduced by 6 dB

Fig. 3-19. Pulse shapes with ultrasonic devices: left HF display, right: rectified

Top row normal display

Bottom row 180° phase rotated

Protective layer, delay path distance

Fig. 3-20. Influence of protective layer or first running distance: For the sake of illustration; the pulses were shifted to the right. RE sequence of 30-mm-thick workpiece; test range: 100 mm. Shift: 10 mm. Workpiece surface: 1. Scale line (zero marking). With correct adjustment, the rising flank of the SI would be half a small line to the left of the beginning of the scale outside of the visible range.

The echo heights visible on the display screen are varied with a gain adjuster calibrated in dB on the device. To double the echo height or reduce it by one half, a change by plus or minus 6 dB is necessary (see section 2.3.1, formula (2-9). However, this is valid only if no threshold value has been set for suppressing small pulses

(Fig. 3-18). If the velocity of sound has been set correctly at a constant value, the time deflection can be calibrated in terms of thickness of the workpiece. In this way the position of the defect can be read especially easily. Ultrasonic units are usually adjusted in mm steel and have test ranges between 5 mm and 10 m for this purpose. However, there is no possibility of adjusting the velocity of sound to be able to represent the distances on the display screen with accurate locations in other materials.

If it is necessary to work with the transmitted sound method instead of the reflection method (see section 3.3), then the switch on the ultrasonic unit between transmitter connection and receiver connection (Fig. 3-16) is opened (S/E transmission/reception instead of instead of S + E transmission + reception). Then a separate test head for the reception of sound may be connected to the receiver bushing E. The same thing is also true of using SE test heads because of their separate transmitter and receiver oscillators. The cause of the presumed instrument failure is often an inadvertently wrongly set SE switch.

Ultrasonic test instruments must be designed for the frequency range in which a test is to be performed. First, the frequency response of the amplifier must be such that it covers a larger range than that determined by the mid-frequency and bandwidth of the test head being used. In the case of ultrasonic test instruments, the -3 dB corner frequencies are usually given for the frequency response of the amplifiers, such that the deviations in frequency response within these frequencies 3 dB. In addition, the frequency spectrum of the transmission pulses must also contain the frequencies which are to be excited in the test head. So-called pulse transmitters that generate an electric voltage pulse with a very short rise time and a somewhat slower exponential drop at their output are widely

used (Fig. 3-21). Typical half-lives $\Delta t_{50\%}$ within which the voltage has dropped to 50% are between 30 ns and 100 ns (Fig. 3-22). In rough approximation, such a pulse transmitter is capable of exciting test heads with frequencies up to an upper limit of $f_0 = 1/\Delta t_{50\%}$. In other words, the frequency spectrum of the transmission pulse here has dropped to 10% of the maximum value. Square-wave transmitters with a variable square-wave width (Fig. 3-22b) are also customary. Their width Δt_R is preferably adjusted to excite oscillation of the respective test head with the mid-frequency f_m to the best possible extent. This is the case for

[insert] (3-5)

The so-called CS transmitters (CS = controlled signals) [27, 28, 29] generates sinusoidal wave trains of adjustable frequency, period and enveloping curve as the electric stimulus signal (Fig. 3-21c). They can also be optimized for the given test head being used in each case.

Fig. 3-21. Transmission pulses of ultrasonic units

a) pulse transmitter

b) square-wave transmitter

c) CS transmitter and enveloping curve.

Fig. 3-22. Pulse transmitter of different width

a) power transmitter, $\Delta t_{50\%} < 60$ ns

b) HF transmitter for highest resolution $\Delta t_{50\%} < 30$ ns.

Fig. 3-23. Selecting test areas with the monitor mask

Fig. 3-24. Test head with LED for signaling defects

To facilitate detection and evaluation of defects, ultrasonic test equipment usually also has one or more monitors. These are additional electronic circuits in the

device, which act only on the part of the A image previously selected with a mask. Masks are used to mark test areas, e.g., by visibly raising the baseline of the cathode beam (Fig. 3-23). All ultrasonic echoes occurring inside the mask are subjected to an automatic analysis in the monitor. In most cases, there is interest only in whether an echo amplitude exceeds or falls below an adjustable signal threshold (monitor threshold). In this case, an acoustic signal is triggered on the device, a warning lamp is turned on and/or a switch signal is generated at the device output. Other external acoustic or optical signals may also be triggered too. If the test operator is unable to observe the screen continuously, e.g., in the case of complex test objects or offshore tests, then the test operator can draw attention to the presence of displays in the expected defect area through earphones or LEDs provided on the test head (Fig. 3-24). In most cases, such monitors also have so-called statistical interference suppression. To prevent random signals from exceeding the monitor threshold, e.g., due to induced electric interference, from leading to misinterpretations, the monitor will display a defect only if the set signal threshold has been previously exceeded at least n times in direct succession. The number n is usually adjustable between 1 and 500. This is known as the interference suppression rate.

However, monitors may also operate by determining the amplitude and transit time of echoes within the mask and applying them to the outputs of the device as analog or digital electric signals. The output signals of the monitors must also conform exactly to the echo amplitudes. We speak here of the *linearity of the monitor*. Depending on their function or output size, monitors are also known as *signal monitors* (yes/no decision and/or output), *proportional monitors* (output voltage proportional to echo height), *transit time monitors* (output voltage proportional

to echo transit time) or *integrating monitors* (output voltage proportional to the area beneath the echo(s)). Monitors permit automatic ultrasonic testing (see Chapter 5). With the help of monitors, however, findings of defects can also be displayed in other ways in addition to the A image discussed above.

Several or numerous A-images are combined here to form so-called B- or C-images. With a B-image, each individual A-image supplies one line of the two-dimensional image and each echo therein supplies one display point. If only those echoes exceeding a set threshold are taken into account, this yields a binary black-and-white (i.e., yes or no) display. However, if the echo heights are imaged in different gray tones or colors in proportion to their heights, the result is analog or weighted B- or C-images. A B-image is formed as a section through a workpiece along a line L on which the test head is moving. The reflections from the interior of the workpiece are visible between the linear summations of the points of transmission pulses and back wall echoes (Fig. 3-25).

The C-image is a top view of the test object, wherein only the defect reflection is projected into the plane of the workpiece coordinates (Fig. 3-26).

If, instead of the echo amplitude, the echo transit time is used for brightness or color control of the pixel, then we speak of a D-image display. As another aid in analysis, many ultrasonic test instruments have an electronic depth equalization. In contrast with the constant gain otherwise set over the entire measurement length, this makes it possible to set the gain as a function of the depth position. Depending on the design of the device, this may be done either continuously or in steps. With depth equalization, for example, all the echoes of a descending

echo train can be regulated at the same height on the screen of the device (Fig. 3-27).

Fig. 3-25. B-image method: The test head is moved along a line (arrow). Defect display through brightness control (after [6]).

Fig. 3-26. C-image display of an internal defect in sheet metal (detail).

Fig. 3-27. Display screen of an echo sequence without depth equalization (top) and with depth equalization (bottom).

A industrial standard (DIN 25450) stipulates the implementing requirements with narrow tolerances for all instrument manufacturers, including the manufacturers of the test heads used,. Similar requirements are being prepared for European standards. In addition, there are currently a number of country-specific standards (e.g., BS 4331 or ESI 98-9).

Fig. 3-28 shows a typical hand testing unit of the customary size in use today. Such devices have small dimensions and low weight. They are battery-operated and are designed for uninterrupted testing for at least eight hours with battery operation and, due to the robust housing, for rough use.

In addition to the analog devices, the ultrasonic device technology, like the trend in oscilloscopes, is also characterized today by digital equipment. Fig. 3-29 shows two digital ultrasonic testers of different design sizes which are customary today. Such devices are also designed for mobile use so they are battery-operated and have a splash-proof housing. In addition to the usually echo display, information about the amplitude, depth and location of a defect echo is here again immediately displayed in plain text in the mask on the display screen for the benefit of the test operator. In addition, the

microprocessor can calculate the substitute reflector size according to the AVG method (see section 3.4.3) and display the result on the display screen. Physical material characteristics such as the velocity of sound and ultrasonic absorption, may automatically also be taken into account by digital equipment.

Digital devices are operated by just a few keypad elements; a large variety of possible settings are opened up by way of a menu on the screen. A scroll-down menu in which all the device functions are described in plain text is especially user friendly. They can be selected by means of a light bar (Fig. 3-30a) which is moved by a hand wheel it the case of the devices from Fig. 3-29. Digital devices also have storage capabilities for measured values, screen contents (A images) and several sets of parameters (Fig. 3-30b). This refers to the complete settings of the device, which can be stored by pushbutton or retrieved at a later point in time. In addition, screen shots of the echo trains can be "frozen" on the display screen and then observed by the test operator at his leisure.

The transmitter and reception amplifier of digital devices correspond to those of analog devices. Their frequency range today goes up to 40 MHz. In contrast with analog devices, however, the echo profile is digitized downstream from the main amplifier (Fig. 3-31) by determining (sampling) the instantaneous amplitude at predetermined intervals of time Δt_A, so-called scanning increments and this amplitude is then saved until the next sampling step [30]. The inverse $1/\Delta t_A$ has the unit of frequency and is referred to as the "sampling rate" or "digitization frequency."

The instantaneous amplitude is given in extremely small units known as quanta. The smaller the units, the higher the resolution. If amplitude scanning is performed, e.g.,

with 8-bit analog-digital (AD) converters, then the amplitude range to be considered is divided into $2^8 = 256$ equal quanta.

Fig. 3-28. Analog ultrasonic tester.

Fig. 3-29. Digital ultrasonic testers of different depths.

To reproduce a sinusoidal oscillation that is true to nature, at least 10 sampling increments are needed. Therefore, the digitization frequency should be ten times greater than the upper cut-off frequency of the amplifier. To reduce the technical circuit complexity, usually several successive pulse cycles of the ultrasonic device are needed for such a dense sampling. In this case, the sampling rate is known as an equivalent sampling rate.

Imaging the digital values point for point on a raster-like display screen of the device yields a digital A-image (Fig. 3-32). The screen resolution is higher, the greater the number of points (pixels) it can display. High-resolution monitor tubes are those with 512 x 320 pixels, as in the device at the top of Fig. 3-29. They give the impression of an analog image because the individual pixels are no longer discernible with the naked eye. Electro-luminescence and liquid crystal display (LCD) screens have a lower resolution (e.g., 320 x 256 pixels as in the device in the bottom of Fig. 3-29) but with a lower power consumption.

These screens are commonly abbreviated as ELD (electro-luminescent display) and LCD (liquid crystal display) screen and allow small device housings because of their flat design. Since LCDs do not have their own light source but instead merely modulate incident or transmitted light, they cannot be read in the dark unless they are separately equipped with an additional background lighting. However, they usually have a high power consumption, so the

operating time with batteries is greatly reduced. Even then, they cannot be read in daylight or artificial light at an oblique angle of viewing. ELD displays do not have this disadvantage because their individual pixels are self-illuminating, like analog ultrasonic devices in television monitors or cathode ray tubes. In a bright environment, especially when working in direct sunlight, it may nevertheless be necessary with the last three types of displays mentioned to darken the screen area by using an attachable sun visor.

Fig. 3-30. Display screen for digital equipment

a) choice of adjustment parameters

b) selecting storage option through luminous bars.

Fig. 3-31. Principle of digitization.

(a)

Echo curve

(b)

Sampling steps

(c)

Echo sampled

(d)

Echo sampled and saved

Fig. 3-32. Pixel display of digitized echoes on display screen raster.

Echo sampled

Assignment

Screen grid

On ultrasonic devices, short transient signals, i.e., signals that are present for only a certain point in time, e.g., an echo that appears only briefly when a test head is moved rapidly over a defect, e.g., echoes with a duration of only 100 nanoseconds - must still be displayed on the screen even when observed over a great measurement length, e.g., with a measurement length of 1 meter of steel, corresponding to a sound transit time of 0.3 ms. A great many individual samples must be processed rapidly to do so. This requires a certain complexity in terms of signal processing and data reduction as well as signal smoothing and processing.

Therefore, the image refresh rate of digital devices - this is the rate at which new A images are written onto the screen - is much lower than the pulse repetition frequency of the transmission pulses. Only in the case of purely analog devices are such rates identical. With values between 40 and 60 Hz the image refresh rate of digital devices is completely adequate for manual testing tasks but not for rapid automatic tests. The decisive advantage of digital devices, however, is that the echoes, screen contents or measured values which are available in digitized form can be printed out directly on a printer or subjected to further signal processing in a computer. These devices therefore have at least one standardized interface - usually a serial (RS232C) interface - which is often designed to be bidirectional. In this case, the devices may also be operated directly from the PC.

Fig. 3-33. Digital wall thickness measuring devices with A-image display.

a) measured value pickup

b) data transmission

Digital ultrasonic devices also offer the possibility of time measurements. The sound transit times between

successive echoes must often be determined because then they can either be used to determine the thickness of a material or, conversely, when the thickness is known, they can be used to calculate and display the speed of sound. In material testing, however, the thickness of a test object is often of interest. This is the case (Fig. 3-33) when, for example, corroded workpieces are to be tested to determine whether the remaining material still have a sufficient strength to withstand further operation with no problem. Consider, for example, pipelines in the chemical industry or pipelines in the oil industry. Therefore, ultrasonic test instruments are often equipped only with a function for measuring wall thickness for the purpose of manual testing. The desired thickness value is then displayed on the screen as a numerical value. The respective echo profile - characteristic at the measurement site is displayed only for control purposes. Transceiver test heads are usually used as the test heads because of their good near resolution and mechanical abrasion resistance (see section 3.1). The measurement range with these test heads is between 0.5 mm and 300 mm. The resolution of these devices is usually 1/100 mm. Such devices always have a large measured value memory so that the measured values determined onsite can be later documented and analyzed in the laboratory (Fig. 3-33b).

Even smaller wall thickness measurement devices (Fig. 3-34) - in pocket format, so to speak - are often used for measuring dimensions in quality control and in a few years should be as widespread as mechanical slide rules (see section 7.2).

Fig. 3-34. Digital wall thickness meter in pocket format.

Meanwhile, it sometimes happens that an ultrasonic tester cannot be set up in the immediate vicinity of the test object and the test head must be connected with a longer

test cable. However, the test result is impaired with increasing frequency and longer cable length because the electric signal is weakened by the cable damping and is reflected back and forth in the cable between the test device and the test head because of the different electric impedances Z. At a propagation rate of the electromagnetic wave in the cable of approx. $2 \cdot 10^8$ m/s, the transit time (back and forth) in a cable 20 meters long is still 20 ns. Multiple reflections may result in unwanted interference, as is the case with ultrasonic pulses, and may completely distort the ultrasonic echo to be imaged on the screen of the ultrasonic tester. This situation can be remedied with an electronic device arranged close to the test head and consisting of a separate electric transmitter and a reception amplifier with an output impedance of 50 ohm, which may also be accommodated in miniaturized form in the test head (Fig. 3-35). The test head here is connected to the sending and receiving bushing of the ultrasonic device via a double cable. The transmission signal of the ultrasonic tester triggers its own electric transmitter integrated into the test head, which is connected to the oscillator. In the case of reception, the electric signal generated by the oscillator is preamplified and goes without reflection over a cable with an impedance of 50 ohm to the input of the ultrasonic device, the latter likewise being closed with 50 ohm.

Fig. 3-35. Ultrasonic test head with integrated electronics.

Fig. 3-36. Test electronics for automatic testing with multiple channels.

High test speeds are achieved by detecting the largest possible areas of a test part with multiple test heads. Industrial ultrasonic electronic testers for automatic testing are therefore fundamentally designed for multiple test channels and multiplex operation. Fig. 3-36 shows an electronic unit intended for 16 test channels and/or test

heads or multiples thereof. Each channel is set via a dialog menu on the screen. The built-in oscilloscope at the top provides a display of the ultrasonic echoes, but is needed only for control in adjustment of the test heads. Amplitudes and transit times of echoes are determined automatically and analyzed during operation. The data management is handled on a PC level. Therefore, a PC is usually incorporated into such devices. Circuit outputs are also obligatory to activate sorting switches in the event of defect findings or to trigger color markings on the workpiece. The actual ultrasonic electronic unit is here again accommodated in immediate proximity to the test heads, i.e., close to the workpiece in a splash-protected and vibration-proof mount. The sturdy transmitter-receiver unit illustrated in Fig. 3-37 contains practically a complete remote-controlled 8-channel ultrasonic test instrument, which must be insensitive to mechanical vibrations or electromagnetic interference - e.g., caused by HF welding systems, which must fundamentally be expected in factory buildings. Details about the automatic ultrasonic testing can be found in Chapter 5.

Fig. 3-37. 8-Channel sending and receiving unit for installation directly at the test site.

5 Automatic Ultrasonic Testing

Each ultrasonic test can be automated with varying degrees of complexity. Automated mass tests are independent of human inadequacies and fluctuations in output. They provide more thorough, more uniform and more reliable results than those that depend on human operators to perform the tests and they are usually also faster. This is especially important in testing for release of defective materials. Any production can be improved by rapid feedback from defective test findings and the resulting changes in production conditions, so there is a steady decline in the number of defective workpieces. Because of the lower incidence, detailed investigations of improperly sorted test objects due to extensive time-intensive manual tests become less important in terms of cost as well.

In each individual case, however, it is necessary to estimate the amount of complexity required to prevent defective parts from passing through undetected. This pertains not only to the design of the test systems but also their operating reliability, e.g., through continuous automatic self-monitoring for constant and uniform operating readiness. This includes signaling for trouble or nonfunctioning as well as the required consequences.

As is already the case in manual testing, the required threshold between good and bad findings must be defined clearly and demonstrated with the help of accurately manufactured test pieces. Natural defects are not suitable for this in most cases because they lack reproducibility. The basic prerequisite is definition of the *expected defect ranges* to be monitored and the anticipated changes in display levels with different depth locations. In addition, another factor to be taken into account is the extent to which geometrically determined ultrasonic displays can influence or distort the test results, given the existing

manufacturing tolerances. Under some circumstances, this may lead to restrictions on the scope of testing that are stipulated as acceptable if they cannot be compensated by other measures.

In today's climate of *product liability*, the limits of relevance of testing must be defined in writing as accurately as possible in the interests of all involved and their acceptance must be agreed upon with the consumer or further consumer. Test procedures that are accepted on all sides contribute toward eliminating the lack of clarity which still persists in this regard in many cases today.

The monitors already mentioned in section 3.2 form the basis of the automatability of ultrasonic testing. These monitors are electronic accessories to the ultrasonic unit, providing reproducible displays of the amplitude and/or transit time of ultrasonic signals, so that signaling, recording and sorting measures are possible without involving human operators. The mask of the monitor is set for the *expected defect range*, depending on the geometry of the test object. A signal monitor shows when an amplitude threshold has been exceeded or, in the inverse test case, when the amplitude falls below the threshold; the transit time monitor shows the distance of a display within the mask from a reference value (Fig. 5-1). Several events may also be detected, added up, linked together or otherwise processed within a mask.

Operating reliability is influenced by various factors. Uniform functioning of sensors as well as the fittings and equipment is assumed to be self-evident today, but special measures are required to ensure uniform coupling between test heads and test objects, in particular in the case of moving test objects. Various techniques are possible here. Fig. 5-2 shows an immersion method, partial immersion method (basin method), gap and water jet coupling (guided

or free) in schematic diagrams. The decision about which method is to be used must be made separately in each individual case. Dimensional stability and/or deviations in the test object play just as important a role as do the surface condition, the required throughput speed and/or ambient influences.

Fig. 5-1. Transit time monitor with display of wall thickness (WD) and velocity of sound (VS).

Contact method	Running water coupling, cuff method	Immersion method
Basin method	Water jet coupling, squirter method (guided)	Water jet coupling, squirter method (free)

Fig. 5-2. Coupling techniques.

Recently, a type of coupling that had been described before but had almost disappeared has been used again: the test heads are arranged inside an elastic wheel filled with coupling fluid and closed. This wheel conforms to the surface of the test object (Fig. 5-3) and therefore only a thin coupling film on the outside is required. Therefore, the demand for coupling medium is greatly reduced. On the other hand, the outer membrane of the wheel dampens the passage of sound, is exposed to constant wear in the rolling movement and may be destroyed by pointed or angular surface defects. Furthermore, the ultrasonic conditions may vary due to the fluctuating geometry and the position of the test object with a rigid wheel axle.

Fig. 5-3. Ultrasonic test wheel

Many test jobs cannot be handled satisfactorily using a single test head. In many cases, several test lanes must be

analyzed simultaneously. The complexity of providing a separate ultrasonic unit for each test head can be reduced if the various test heads are switched to the same electronic analyzer one after the other. This is done by using so-called multiplexers. This reduces the *pulse repetition frequency* (*PRF* - using the English term) per test lane in proportion to the number of test heads. The higher the PRF, the faster the test speed can be but also the greater the wear between the test head holder and the test object passing through. To obtain optimal data, it is first necessary to define which *throughput* must be reached. In the case of roll-rough surfaces and mechanical test head guidance, a speed of 0.5 to 1.5 m/s, corresponding to 30 to 90 m/min, should not normally be exceeded. Furthermore, it is necessary to define how many test pulses strike one continuous defect as a minimum. The minimum number is 1, but it must be higher if interference pulses, e.g., from welding machines or crane motors that induce voltage peaks in sensitive ultrasonic amplifiers and may therefore be interpreted as echoes due to defects, must be expected. To rule out this possibility, statistical interference suppression is used; in this method, a defect signal is output only when the defect echo exceeds the preset threshold in several successive pulses (see section 3.2). Example: if the effective sound bundle width of the test head B_{PK} is 10 mm and if the smallest defect to be displayed has a diameter D_{min} of 1 mm, then with a PRF of 1 kHz, the interference suppression rate would be max. 10 if the defect passes by at a rate of v = 1 m/s. If the *interference suppression rate* could be reduced to one half (5), then the throughput could be doubled, i.e., to 2 m/s.

The maximum possible PRF also depends on technical factors pertaining to the testing. The transit time of the ultrasonic pulse is obtained from the test head distance and the workpiece thickness, depending on the velocity of sound, in the coupling layer and the test object. The next

text pulse may be triggered only after a certain minimum time in order to avoid interference due to phantom echoes (see Fig. 3-17). Thus the maximum PRF of each individual test channel is determined in this way. In practice, these values will be between 100 and 1500 Hertz (pulses per second). To comply with the values specified in the aforementioned example (B_{PK} = 10 mm, D_{min} = 1 mm, 10 x interference suppression, v = 1 m/s), a PRF of min. 1 kHz (1000 pulses per second) is necessary. If it is necessary now to work with four test heads simultaneously, for example, then the pulse generator which excites all test heads in succession (sequentially) must work with at least 4 kHz. System electronics allow a PRF of 20 kHz or more. This makes it possible to operate *multichannel systems*. If their maximum PRF is not sufficient, then several systems must be used in parallel.

Display probability

Response threshold

Uncertainty range or gray range
for method B

Size of defect or signal

Fig. 5-4. Toward a definition of the uncertainty range in ultrasonic testing and other non-destructive test methods [127].

Since the electronic testing and analyzing equipment cannot usually set up directly at the test site, only the pure ultrasonic electronics consisting of at least one transmitter and one preamplifier each per test head will be set up jointly right by the test heads, often with additional main amplifiers (see section 3.2, Fig. 3-37).

Individual fluctuations in sensitivity of the various test heads can be compensated with the preamplifier. The amplifiers usually have output impedances which are adapted to the cable impedances of coaxial lines (e.g., 50 ohm). In this way, signals may also be transmitted over greater distances to the electronic testing equipment and line wave reflections can be avoided.

In each individual case, the reproducibility with which a defect evaluation can be performed in ongoing operation, i.e., with a moving test object, must be checked. For example, if the display height of a test defect is set exactly at the display threshold of the monitor in a static preliminary test, i.e., with the test object stationary, then the result will only rarely be *sorting findings* that are completely identical in multiple automatic passes of the same test item. This denotes the proportion of test objects found to be good or bad. This is caused simply by fluctuations in coupling, shape tolerances in the workpiece and the resulting difference in occurrence of test pulses on the workpiece. By increasing the test sensitivity, a *sort out rate*, i.e., the percentage of test objects sorted out and found to be bad, of almost 100% can be achieved, but by reducing the test sensitivity, a reproducible good finding is obtained. The sensitivity range between 0% and 100% probability of display is referred to as the "*gray range*" (Fig. 5-4) [127]. This describes an important property of the test method used. The converse of the rule of thumb with the display probability is the case with discarding defect-free test objects. The greater the test sensitivity, the greater is the risk that usable workpieces will be sorted out incorrectly as being defective. These are also known as *pseudo-rejects*. According to the so-called *ROC method* (*relative* or *receiver operating characteristic*), the display probability of real defects (w_p) and pseudo-rejects (u_p) can be related visually [128]. Of the set of curves shown in Fig. 5-5, five describe the

characteristics of the best test system and one describes the characteristics of the worst test system. Such comparisons are appropriate not only for evaluation of different ultrasonic systems but also various test methods that can be applied to the same object. Completely different curves may result for different types of defects.

Fig. 5-5. Probabilities of real (w_p) rejects and pseudo-rejects (u_p) with various test systems (1-5) [128].

In this book so far, only ultrasonic testing has been described in all its varied possibilities as well as its limits. On reaching the limit ranges and also in considering the cost of testing, one factor to be taken into account is whether other non-destructive test methods are technically better or less expensive alternatives. These must first be described briefly to permit a factual comparison.

8.1 Radiographic testing using X-rays and gamma rays

X-ray equipment supplies radiation of a lower energy, i.e., a longer wavelength, so-called "softer" radiation than the gamma rays of radioactive isotopes, e.g., iridium 192, cobalt 60 and recently selenium 75. The radiographic suitability is therefore lower but detail recognition is better. It is known that humans must be protected from radiation damage. Expert personnel must ensure compliance with applicable regulations. This is simpler with X-ray equipment because such equipment can be turned off; isotopes, however, cannot. Therefore, the latter must be stored in suitable working containers in which they are shielded. Therefore, the advantage of easier handling in comparison with X-ray equipment is lost under some circumstances. Furthermore, isotopes become weaker over time. Their intensity drops to one half in the so-called *half-life*.

Surely everyone has experienced *X-ray testing* at least once on his/her own body. Just as in medical diagnostics on the human body, the welded joint to be tested is placed between the radiation source and the radiation detector. Either an X-ray device or a radioactive isotope is used as the radiation source. In both cases, electromagnetic waves pass through the test object. They become weaker in their passage through the object, and this effect is greater, the greater the amount of material through which the radiation must pass. The proof of the remaining intensity after radiography is usually obtained in industrial practice with the help of film (Fig. 8-1 in non-destructive test less frequently - and more frequently in medicine - with image amplifiers and even less frequently with a connection to image processing systems. Differences in intensity are manifested through differences in optical density on the

film (Fig. 8-2). It is self-evident that bulky defects in an object that has been radiographed will appear more distinct than shallow defects, e.g., cracks, which become apparent only when the direction of incident radiation is selected to be parallel to the path of the crack.

Radiation source

X-rays

workpiece

cavity

X-ray film

amplifier films

Fig. 8-1. Principle of radiographic testing [232].

Therefore, radiographic testing is more suitable for testing for voluminous internal defects such as pores, shrink holes and the like than for two-dimensional and linear defects such as cracks. Additional literature on the topic of radiographic testing can be found in the articles [19, 227-233].

Fig. 8-2. Transmitter radiation micrograph of a weld with pores and a crack perpendicular to the surface [233].

8.2 Eddy current testing

The use of eddy current testing for crack testing is based on the fact that surface cracks lead to a disturbance in the course of eddy current lines on the workpiece surfaces, which are in the effective area of a continuous coil or an exploring coil, through which an alternating current is passing (Fig. 8-3). Therefore, the normal feedback effect on the primary AC field of the coil changes and there is a change in the impedance in coils with just one winding (parametric coils) or a change in signal voltage on coils with a primary and secondary winding (transformatory coils). In principle, parts made entirely of electrically conducting materials can be tested for surface cracks by eddy current testing. It is a disadvantage that a number of other influences such as changes in thickness, mill scale, fluctuations in conductivity and permeability can also affect the test results. Most of these interfering influences have different effects on the amplitude and phase of the signal voltage than a crack and therefore can be eliminated. The influence of permeability poses problems with ferritic steels because its effect on the signal voltage is similar to that of a change in diameter in a cylindrical coil or lifting an exploring coil from the part to be tested. To ... the influence of permeability ...

Fig. 8-4. Stray magnetic flux developing across a crack.

...is known [as] *-graphy*. In the simplest case, the magnetic tapes may be placed on the magnetized surface of the part to be tested. However, the magnetic tape may also be unrolled over the surface as continuous tape, repeating the influence of stray flux, stray flux sampling and demagnetization of the tape in a steady sequence.

Magnetography has been used on a large scale in pipeline testing in Russia because the requirements of defect detectability are relatively low there. Testing with stray flux probes including magnetography makes it possible on a limited scale to detect even cracks lying just beneath the surface.

Fig. 8-5. Revealing cracks with magnetic powder on a pipe weld.

Test medium always added from above

optimal
(surface crack)

possible
(crack just beneath the surface)

impossible
(internal crack)

possible
(lower sheet thickness)

impossible
(crack parallel to magnetic flux)

Fig. 8-6. Detectability of cracks at and beneath the surface.

The most widespread method of stray flux testing is *magnetic powder crack testing*. The stray flux attracts

magnetic powder particles. Since stray flux and a powder bead are wider than the top edge of the crack, this results in a display that is visible to the human eye, especially when there is a definite color contrast between the powder and the surface of the workpiece. This is the case in particular when the powder particles are associated with a pigment that is *fluorescent in ultraviolet (UV) light* (Fig. 8-5). Even very fine surface cracks with depths in the µm range are reliably displayed even if they are filled with oil, dirt or corrosion products. The display of internal cracks is not out of the question but is problematical because the formation of stray flux at the surface depends not only on the distance from the surface but also on the shape and size of the separation (Fig. 8-6).

In any case, the magnetic flux required for the display must strike the crack at a right angle or must at least have a definite component in this direction. This is the case if the two directions differ by at least 30°. For detection of cracks of all directions, therefore two magnetization directions that are offset by 90° in relation to one another must be selected. Alternatively, two magnetizations at right angles to one another may be applied simultaneously. However, the two magnetizations must behave differently in time, so the direction of the respective active composite magnetization vector must be perpendicular to cracks of all directions in succession.

Magnetic powder crack testing can also detect cracks directly beneath the surface and/or beneath a thin layer of paint or electroplating, but is limited to ferromagnetic (= magnetizable) materials [1].

Recently, computers that apply pattern recognition algorithms to the images of a CCD camera have also been used for automatic crack detection [244].

8.4 Penetration testing

Dye and fluorescence penetration testing are the most widely used methods of surface crack testing when the parts to be tested are not ferromagnetic. These methods have proven successful with metallic materials as well as nonmetallic materials (in addition to porous materials).

As in magnetic powder crack testing, a crack is also imaged as distributed on the workpiece surface in dye penetration testing. Therefore, the workpiece and the crack must be cleaned carefully in a first operation (Fig. 8-7). After removing the cleaning agent, a *colored or fluorescent penetration agent* which has a low viscosity is applied; this agent can even penetrate into fine cracks due to a capillary effect.

After a penetration time which depends on the viscosity and is between a few seconds and a few minutes, excess fluid is removed from the surface. Then a so-called developer fluid which contrasts with the penetration agent is applied; after drying, this developer fluid attracts the liquid that has already penetrated into the cracks like blotter paper and thereby makes the course of the crack visible (Fig. 8-8).

Penetration testing can only reveal cracks that are open to the surface but can detect them in any solid material.

There are numerous variants of penetration testing, but all of them are based on the same fundamental principle. The aviation and space industry tests turbine blades and other parts in semiautomatic processes in large closed immersion systems.

Only rarely is the *oil boiling test*, the oldest penetration method, used. In this method the parts which have been previously cleaned and degreased are heated in a hot oil. In this process, the oil penetrates into the surface cracks. If the parts are allowed to cool in air after being removed from the oil and then coated with Spanish white, i.e., prepared chalk, the oil is forced out of the cracks when the parts cool and then is absorbed by the slurry chalk, leaving behind a dark tracing in the layer of slurry chalk that serves as a developer.

The pickling test is a special penetration method which works without a developer and in which the pickling fluid remaining in surface cracks leads to chemical reactions and thus to discoloration of the surfaces. By descaling the upper edges of the crack, this also results in a visual broadening of the display. Pickling is not favorable for a subsequent magnetic powder crack testing because of the rounding of the edges.

cleaning

applying penetration agent

waiting for the penetration time

penetration time concluded (removing excess penetration agent)

applying developer

waiting the developing time

inspection (display of cracks)

Fig. 8-7. The individual steps in dye and fluorescence penetration testing.

Fig. 8-8. Pipe weld from Fig. 8-5; crack detected by the penetration method.

8.5 Potential probe method

In a defect-free material, the same voltage drop will occur on each section of the surface of a conductor of the same length with a current passing through it. However, if there is a surface crack, the voltage drop will be increased in proportion to the crack depth because the path of the current thread is lengthened around the crack (Fig. 8-9). This measured value can be calibrated directly in millimeters of crack depth by using a suitable sensitive measurement technique [235, 236].

Fig. 8-9. Principle of the potential probe method for measuring crack depth
a) arrangement, b) voltage curve.

8.6 Magnetic induction

The magnetic flux in a coil through which current is flowing changes when ferromagnetic materials are brought into its effective range. If workpieces of ferromagnetic steel, e.g., forged or cast automotive connecting rods of the same dimensions are placed within a coil one after the other, always in the same position (Fig. 8-10), then the resulting changes in magnetic flux are the same if the magnetic and electric properties are also the same. However, these properties vary with the composition of the material (alloy) and the structural condition. Therefore, mix-ups in material, differences in batches, structure and hardness can all be detected in this way [237, 238].

If an open coil or a coil provided with an iron core is brought into proximity to a ferromagnetic body, its inductance L and/or electric impedance changes as a function of the distance (Fig. 8-11). This phenomenon can be utilized to measure the thickness d of nonmagnetic layers, both conducting and non-conducting [239] by measuring the respective coil voltage at a fixed current I.

Fig. 8-10. Magnetic inductive structure and identity testing device.

air gap F

F = cross section,

μ = permeability

magnetic probe

device

display

printer

characteristic line

memory

keyboard

Fig. 8-11. Basic principle of the magnetic inductive layer thickness measurement; top: two-pole measurement probe; bottom: instrument design with a single-pole probe.

8.7 The sound emission analysis

With this method, an attempt is made to test entire components globally for cracks. This is possible only in the case of active cracks, i.e., cracks that grow under mechanical, thermal or corrosive stress. The resulting sounds, which are not audible to the human ear, can be detected with suitable sensors and amplifiers. This always requires a load on the component. Interpreting the signals requires a great deal of experience. Test costs can be minimized if test objects without critical cracks can be rapidly differentiated from those which must be retested

with the usual methods of non-destructive crack testing through a choice of suitable load conditions.

The most important applications are for monitoring boilers and pressure vessels.

8.8 Thermal methods

If a uniform workpiece is heated uniformly, the result is a uniform temperature on its surfaces. This uniformity can be disturbed by internal and/or external defects. The presence of defects can be deduced from the resulting temperature differences or profiles. Detection can be performed using test media that change color on reaching certain temperatures or with infrared detectors and/or cameras. The best-known applications are the discovery of bonding defects in composite materials, detection of surface cracks on steel billets and - outside of non-destructive testing - the efficacy of thermal insulation measures on buildings.

8.9 Visual inspection

The oldest and simplest method of testing for cracks that are open toward the surface and other surface defects remains visual inspection, i.e., visual testing. With poor access to the surface area to be tested and with especially high demands of defect detectability, visual aids such as a magnifying glass, an endoscope and video cameras may be used. To a certain extent, automation is conceivable with use in video technology. Visual detectability of cracks can be improved significantly by using lighting that enhances contrast, by performing descaling and surface cleaning before performing a test and by using special pickling agents.

8.10 Ultrasonic testing in comparison with other non-destructive test methods

In Tables 8-1, 8-2 and 8-3, the other non-destructive test methods that have already been presented in this chapter are compared on the basis of their physical principles, the advantages, disadvantages and limits of ultrasonic testing.

Only the most widely used ultrasonic method, namely the pulse-reflection method, was used as the basis for all comparisons. It would reduce the simplicity of the overview to additionally include the sonic testing method.

The tables differ in some regards from those in previous publications [240, 241]. The following explanations are called for here.

Table 8-1 describes the physical effect on which the individual non-destructive test methods are based in terms of testing technology and not just physically. In principle, all non-destructive test methods are suitable for determining defects. There are restrictions in the case of the potential probe method and in sound emission testing. It is tedious to search for defects with a potential probe at least when the location of occurrence of the defect is not fixed from the beginning due to the type of stress and/or the geometry of the workpiece. Therefore, crack depth measurement will usually be proceeded by a large area crack testing according to the magnetic powder method or the penetration method.

The development and/or growth of cracks is/are usually but not always associated with the occurrence of detectable sounds in the ultrasonic range. Therefore, a quantitative defect detection with the help of sound emission is inferior in comparison with all other non-destructive test methods. It is possible to determine the location of a defect with all other test techniques although not equally well or equally completely. For example, it is thus much more possible to locate a defect with ultrasonic testing, i.e., determine the depth position of a defect in comparison with the radiographic method. In the display of the defect dimension parallel to the surface, however, the relationship is exactly reversed. The probability of discovery and the certainty of display are different in

crack testing methods. These differences cannot be illustrated in the form of the shortest possible tables, however.

Given the width of application technologies customary today with the non-destructive test methods, a general comparison is difficult. This is true in particular for the costs as shown in Table 8-2 for the test performed manually. Automatic test systems and large-scale tests, e.g., in the automotive field are explicitly excluded here.

If the training costs are based on step 3 according to EN 473, if the test equipment costs are based on the prices of handheld devices plus accessories and consumable materials and if performance costs are based on the time required, e.g., for one meter of weld or a certain number of tests, then the numbers given in Table 8-2 give approximate comparative values.

Some methods would have to be subdivided into multiple methods for more accurate evaluation. The thermal methods, for example, include not only the use of layered materials which respond to changes in temperature with a change in color, but also ...

Table 8-1. Non-destructive test methods

Test methods	Physical effect	Can be used for:				
		defect testing	determining defect location	determining defect size	determining material properties	measuring dimensions
ultrasonic (pulse reflection method)	reflection on interfaces	yes	yes	yes, but only in comparison with other reflectors	yes, velocity of sound, elastic modulus	yes, distance, wall thickness
radiography with X-rays and gamma rays	different absorption in different materials	yes	yes, in film plane, not in direction of beam	yes, in film plane, limited in direction of beam	yes, with X-ray fine structure equipment	yes, measurement of strip and film thickness
eddy current	change in and interference of eddy current fields	yes	yes	yes, at the surface, not below	yes, conductivity permeability	yes, layer thickness
stray flux testing by probes, etc. or magnetic powder	formation of stray flux at the surface	yes	yes, at the surface, not below	yes, at the surface, to a limited extent deep in the crack	no	no
penetration method	capillary effect	yes	yes, only at the surface	yes, at the surface, to a very limited extent in the depth of the crack	no	no
potential probe	measurement of voltage drop in a current path	yes, but only when the location of any crack is known	no	yes, depth of surface cracks	no	yes, wall thickness
magnetic induction	change in magnetic flux	limited	limited	limited	yes, under certain	yes, under certain

					prerequisites of hardness, structural development	prerequisites of length, diameter, thickness, layer thickness
sound emission	noise produced with development and growth of defects	yes	yes, with several sensors	no	no	no
thermal methods	development of temperature profiles due to different thermal conductivity and specific heat	yes	yes	limited	limited	no
visual inspection	detection of differences in brightness, shape and color and/or states by the human eye, including with auxiliary means	yes	yes	yes, at the surface, not below	very limited	yes

Table 8-2. The applicability of the non-destructive test methods

Test methods	Especially suitable for	Automatable	Special advantage in comparison with other methods also suitable	Limits of method	Cost per 1 (low) to 10 (high) for: training for testers	test materials and equipment	performing the test
ultrasonic (pulse reflection method)	detection of flat and bulky internal defects, measurement of (remaining) wall thickness	yes	great range (no restriction due to workpiece thickness), versatile application: internal and external defects (equally well detectable)	defect size can be estimated only by comparison, interpretation is difficult	10	9	8
radiography with X-rays	detection of voluminous internal defects	not yet, possible in the future	documentation of the real defect image on a film, better detail recognizability than with gamma rays	workpiece thickness, cracks can be detected to a limited extent	9	8	10
radiography with gamma rays	detection of voluminous internal defects	not yet, possible in the future	greater workpiece thickness can be tested than with X-rays	workpiece thickness, cracks detectable to a limited extent	8	7	9
eddy current	surface cracks	yes, high test speed	crack detection in nonferrous metals	can only be used with electrically conducting materials	7	4	6
	layer thickness measurement	yes	no coupling means		2	1	1
stray flux testing by probe, etc.	surface cracks	yes	less interfering effects than with eddy current	can be used only with ferromagnetic materials	7	8	6

Table 8-2: (continued)

stray flux testing with magnetic powder	surface cracks	not yet, possible in the future	crack position and length clearly visible, easily analyzed, low influence of workpiece geometry and surface structure, high sensitivity	only applicable with ferromagnetic materials	4	5	5
penetration method	surface cracks and pores	limited	no apparatus required regardless of geometry of test object	defects must be open to the surface, not suitable for porous base materials	2	2	3
potential probe	measurement of depth of surface cracks	no (only in special cases)	exact crack depth measurement	cannot normally be used to detect cracks	3	4	4
magnetic induction	testing for mix-ups and structural testing layer thickness measurement	yes yes	rapid testing of mass parts	no coupling means required, can be used only with ferromagnetic materials	6 2	6 1	6 1
sound emission	detection of crack development and growth	yes	testing of entire structures, suitable for early detection of damage	quantitative statement hardly possible, relevance in changes in loads better than in static operation, secondary noise causes interference	6	10	7
thermal methods	discovery of bonding defects and surface separations	very limited	surface analysis	only with a uniform geometry; findings change over time	5	3	2

visual inspecti on	large surface cracks detectable [illeg.]	limited	without complexity	subjective, no auxiliary means required, low sensitivity	1	1	1

Table 8-3. Advantages and disadvantages of ultrasonic testing

Ultrasonic testing has ... in comparison with	Advantages	and Disadvantages
all other non-destructive test methods	rapid and reliable detection of internal and external defects in all workpieces that conduct sound	objective documentation difficult in manual testing
and in addition in particular with respect to radiographic testing	no radiation protection required, accessibility from one side of the test object is sufficient	greater subjective influences in repeat tests
eddy current testing	detection of the entire cross section of the test object	need for coupling, lower throughput
stray flux testing by probes, etc.	detection of the entire test object cross section	need for coupling
magnetic powder	can be automated much better	depends greatly on the geometry of the test object, less sensitive, lower signal-to-noise ratio and contrast
penetration methods	can be automated much better display even with closed surface defects or corrosion	same as with magnetic powder
potential probe	measurement of crack depths even with interrupted cracks	accuracy of depth measurement at surface cracks much lower
magnetic induction	few compatible applications	structural differences can be detected with lower sensitivity lower resolution in layer thickness measurement
sound emission	quantitative conclusions possible	no rapid overall evaluation of components possible
thermal methods and visual inspection	there are hardly any applications with the same test problems	